# Conservatism Implications of Shock Test Tailoring for Multiple Design Environments

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Specification of a mechanical shock test requires an engineering decision concerning the relationship between the laboratory and field shock environments. Once a method of shock characterization is selected, test conservatism becomes a measure of the degree to which the laboratory test is more severe than the operational environment of the structure being tested. This paper describes a method for analyzing shock conservatism in test specifications which have been tailored to qualify a structure for multiple design environments. Shock test conservatism is quantified for shock response spectra, shock intensity spectra and ranked peak acceleration data in terms of an Index of Conservatism (IOC) and an Overtest Factor (OTF). The multi-environment conservatism analysis addresses the issue of both absolute and average conservatism. The method is demonstrated in a case where four laboratory tests have been specified to qualify a component which must survive seven different field environments. Final judgment of the tailored test specification is shown to require an understanding of the predominant failure modes of the test item.

## INTRODUCTION

Tailoring test specifications for shock-hardened components requires an engineer to relate the laboratory test environment to the field shock environment in the most meaningful way possible. This process is critical since "overtesting" may require expensive design modifications to the component, while "undertesting" will sustain uncertainty regarding the survivability of the component in the field. The fundamental problem becomes one of operationalizing the analyst's engineering judgment about test conservatism into a consistent and quantitative methodology. This process is complicated further when the component must survive more than one field environment. An engineer typically utilizes data measured from the operational shock environment as the basis for selecting the qualification test method and test level. Test conservatism is a measure of the degree to which this tailored laboratory shock environment exceeds the field environment. Even though it is rarely evaluated in a quantitative manner, a level of test conservatism is implicit in every test specification. In this paper, a method is presented and demonstrated for

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assessing conservatism in shock test specifications tailored for multiple field environments.

Description of the conservatism analysis procedure will be presented by example. Shock data for an electronics package subjected to both operational and laboratory mechanical shock tests will be analyzed in the course of performing the conservatism assessment. The discussion will cover: 1) the original tailoring of the the test specification considering multiple environments; 2) the initial evaluation of conservatism; 3) the specification of a level of conservatism for judging an overtest condition; 4) the identification of overtest and undertest conditions; and 5) and the interpretation of the results in terms of possible failure modes of the component.

## SHOCK TEST TAILORING

A common shock test tailoring procedure [1] is based on matching the absolute acceleration shock response spectra (SAA) [2] of the field data and a laboratory test input. If multiple field environments exist, then the test is specified to have a SAA spectrum which envelops the SAA of the field data. For the component being discussed in this paper, the field design environments consisted of six measured and one analytically predicted responses of the component in its longitudinal (X) and lateral (Y) axes. Figures 1A and 1B show the ensembles of SAA spectra for these environments. The field environments are denoted with regard to the fact that they are either derived from blast (B) or nonblast (NB) environments. These operating environments include: 1) three different impulsive shock tests (NB1, NB2, NB3); 2) one induced thermo-structural response (NB4); 3) two blast tests (B1 and B2); and one analytical prediction of a different type of blast loading (B3). Envelopes showing the distinction between the blast and nonblast environments are shown in Figures 2A and 2B. In general, the blast environments dominate the low frequency range (i.e., 100 Hz to 1000 Hz), while the nonblast environments control in the high frequency range (i.e., 1 KHz to 10 KHz). All of the data were lowpass filtered at 10 KHz and a 20 ms duration were analyzed for each record.

A resonant plate shock test technique [3] was chosen as the test method. This technique produces high level, two-sided shock inputs which are more similar to the field data than a one-sided haversine pulse which is generated using a drop table shock machine [4]. Two resonating plates were chosen with primary resonant frequencies of 250 Hz and 3000 Hz. The component test specification required that the component survive shocks on the low and high frequency plates in both the X and Y axes. Figures 3A and 3B show a comparison of SAA spectra for the field and test environments. The test designation is a three letter code denoting: the resonant plate used (H for the high frequency plate and L for the low frequency plate); the component axis aligned with the test input direction (X or Y); and the orientation of the accelerometer at the base of the component during the test (X or Y). For example. HYX is the measured X axis input during the Y axis high frequency plate test.

These tests were judged to be acceptably tailored given the constraints of seeking a minimum number of different test setups, and accepting partial enveloping of the X axis shock spectra in the high frequency range. Note that the X axis high frequency range controlled selection of the high frequency plate test while the Y axis low frequency data primarily influenced tailoring of the low frequency plate test.

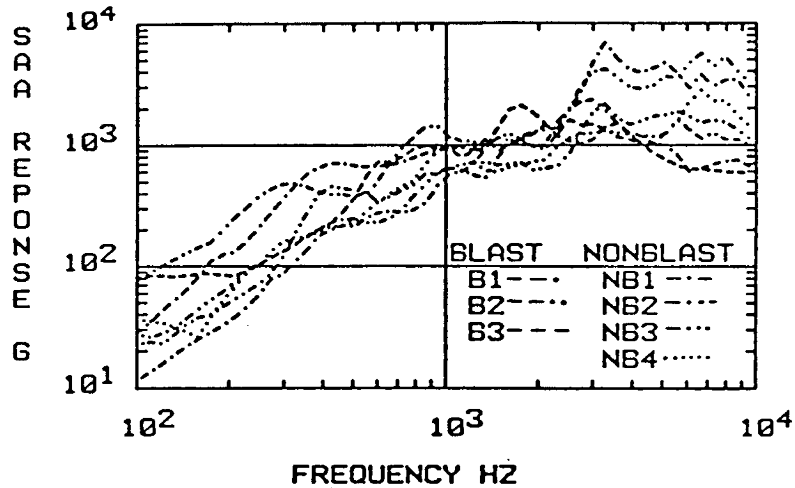



FIGURE 1A.
COMPARISON OF X AXIS SAA RESPONSE FIELD DATA
(DAMPING=0.05)

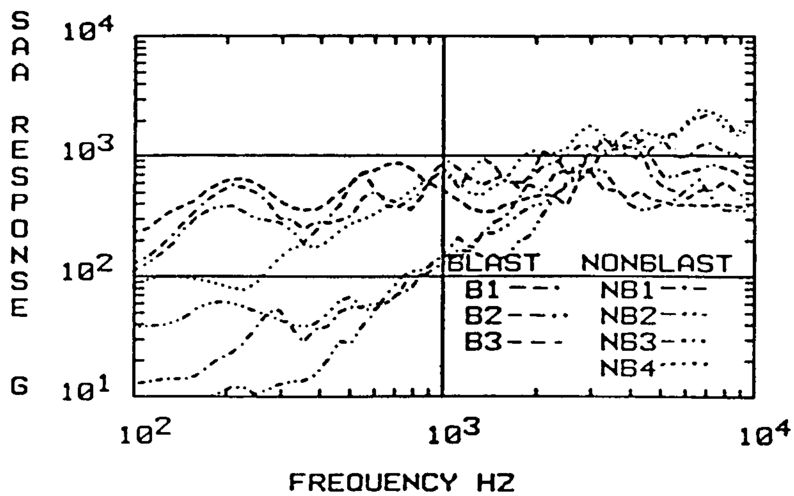



FIGURE 1B.
COMPARISON OF Y AXIS SAA RESPONSE FIELD DATA
(DAMPING=0.05)

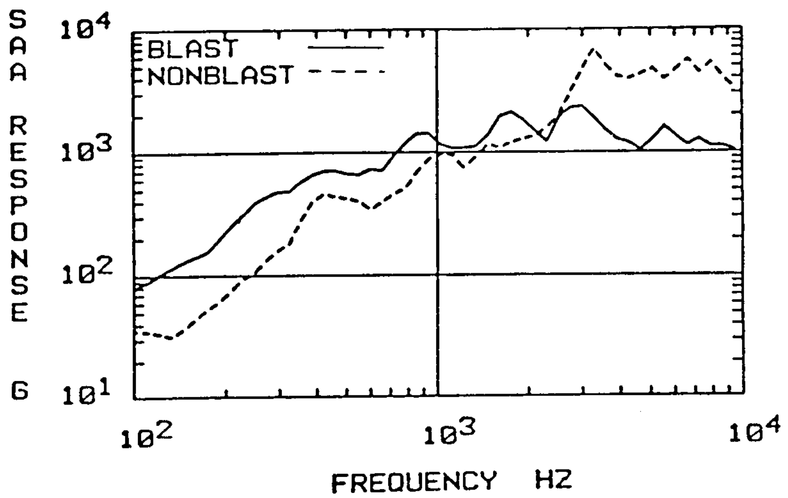



FIGURE 2A.
COMPARISON OF BLAST & NONBLAST X AXIS SAA FIELD DATA ENVELOPES
(DAMPING=0.05)

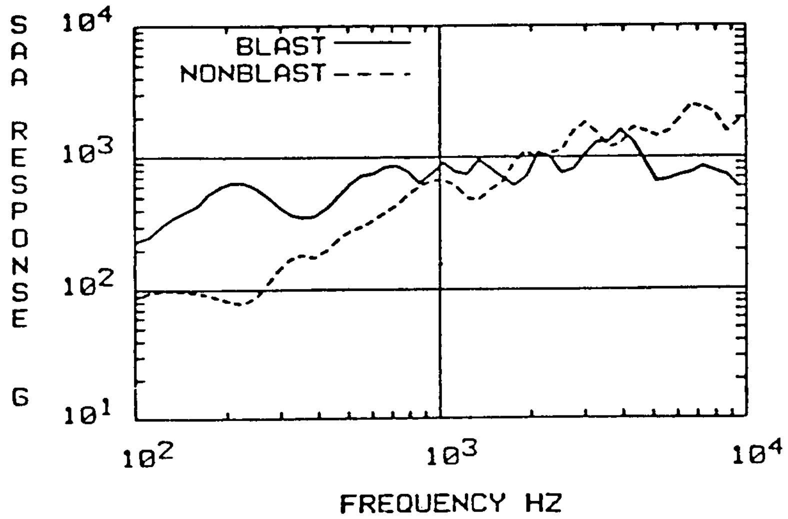



FIGURE 2B.
COMPARISON OF BLAST & NONBLAST Y AXIS SAA FIELD DATA ENVELOPES
(DAMPING=0.05)

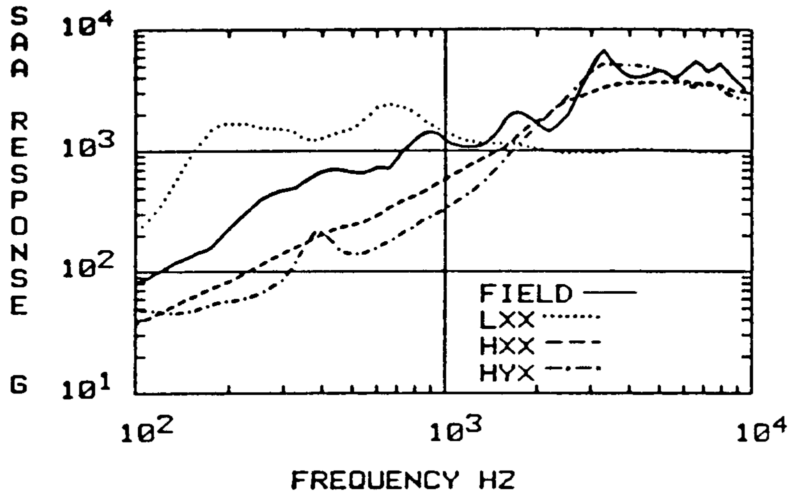



FIGURE 3A.
COMPARISON OF X AXIS SAA FIELD DATA ENUELOPE AND THREE TEST INPUTS
(DAMPING=0.05)

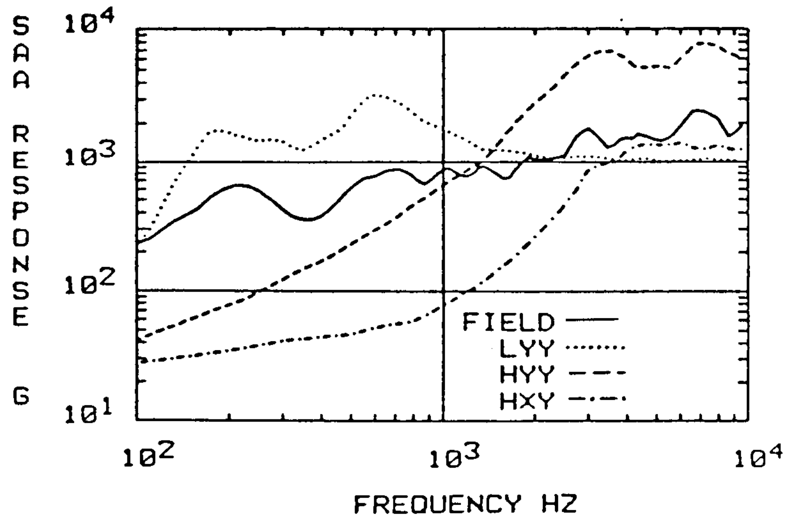



FIGURE 3B.
COMPARISON OF Y AXIS SAA FIELD DATA ENUELOPE AND THREE TEST INPUTS
(DAMPING=0.05)

## MULTIPLE ENVIRONMENT SHOCK CHARACTERIZATION

Even if the shock test is specified on the basis of the SAA spectrum, it is not necessary to restrict the conservatism assessment to that sole shock characterization. The advantages of utilizing alternative shock characterizations have been demonstrated in previous studies of shock conservatism involving single field environments [5-8]. Primary attention will be focused on the shock intensity spectrum (SIS) which is a plot of the contribution of each frequency band shown to the overall rms acceleration of the shock transient [8]. The SIS has the advantage of being a direct indicator of frequency content of the shock signal, while the SAA represents the single degree of freedom response to the shock transient as a function of the natural frequency of the SDOF resonators. Additional mention will be made of the ranked acceleration peaks, with particular attention being paid to the highest peak value (TPK1) as a meaningful shock characterization.

These shock characterizations were computed using the SHARPE computer code [5,8] for all of the field and laboratory test data. The blast and nonblast envelopes of the X axis field test SIS spectra are given in Figure 4. Note the lack of frequency content in the blast data above 3000 Hz. A comparison between an envelope of all of the field data and the lab test data is shown in Figure 5. The predominant frequency of the low frequency plate is shown to actually be at 180 Hz. The question of statistical variation of a shock environment characterization must also be considered prior to the conservatism analysis. This is a difficult question because of the paucity of field data normally available at the time the test is specified, so it is rarely answered. Since all seven field environments considered in this study were different, each field environment characterization is considered as an average value having a coefficient of variation of 0.15. This introduces a variability factor into the field data which may be optimistic (i.e., it may be difficult to verify the accuracy of the measured or analytical data with this degree of refinement), but previous studies [8] indicate that this is a reasonable value. The statistical variation of the laboratory tests was dealt with by repeating each test ten times. Mean values and standard deviations were also calculated by the SHARPE code for the ensembles of laboratory test data.

## CONSERVATISM CRITERIA

The index of conservatism (IOC) [5] provides a quantitative criterion for evaluating shock conservatism. Calculating the IOC for a particular shock characterization C requires that the mean and standard deviations of the field and test be provided by the analyst. Representing the mean values as $\bar{C}_T$ and $\bar{C}_F$, and the standard deviations as $\sigma_T$ and $\sigma_F$, where T and F denote the lab test and field environments, respectively, the IOC is defined as:

$$IOC = \frac{\bar{C}_T - \bar{C}_F}{\sqrt{\sigma_T^2 + \sigma_F^2}} = \frac{\bar{M}}{\sigma_M} \qquad (1)$$

where $\bar{M}$ is the mean margin of conservatism and $\sigma_M$ is the standard deviation of the margin of conservatism. Figures 6 and 7 depict the relationship between these field and test environment parameters. These figures also emphasize the fact that when the mean margin of conservatism is zero, the mean field and test environments are the same on the average, but some of the time there is an overtest or an undertest.

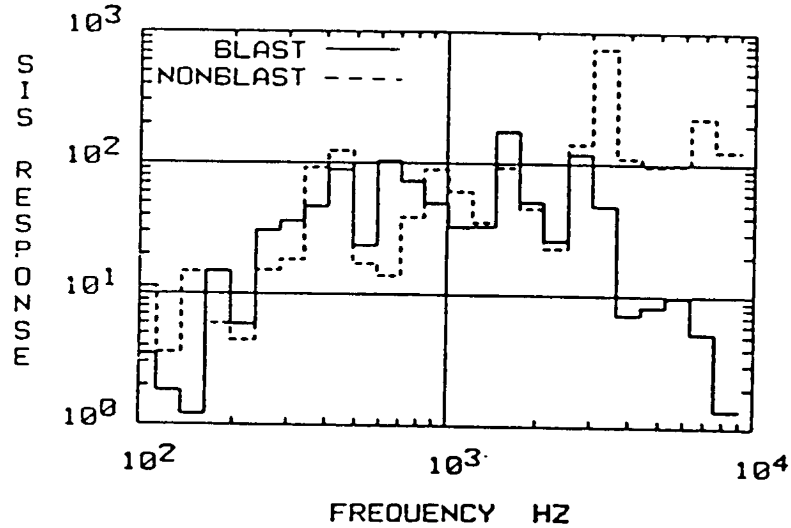



FIGURE 4.
COMPARISON OF BLAST & NONBLAST X AXIS SIS FIELD DATA ENVELOPES
(DURATION=0.02)

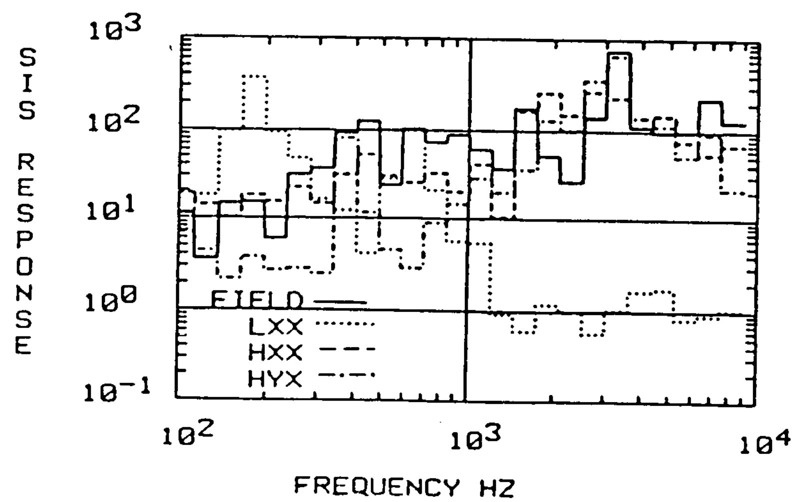



FIGURE 5.
COMPARISON OF X AXIS SIS FIELD DATA ENVELOPE AND THREE TEST INPUTS
(DURATION=0.02)

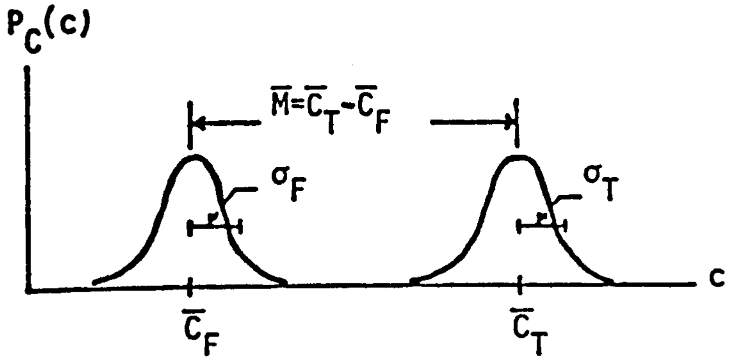



Figure 6 Probability Density Functions of Field and Laboratory Test Shock Environments

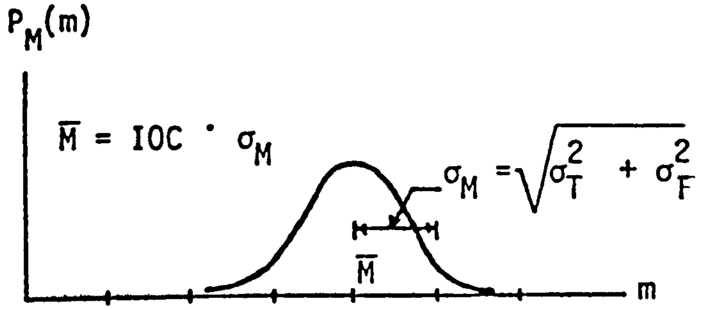



Figure 7 Probability Density Function of the Margin of Conservatism M

Initially in this study, a test is considered conservative if the IOC is greater than zero. This criterion is the basis of a conservatism binary index ($CBI_j$) which is defined for N different field tests under study:

$$CBI_j = \begin{cases} 0, & IOC_j < 0 \\ 1, & IOC_j \geq 0 \end{cases} \qquad j = 1,N \tag{2}$$

Once the CBIj is calculated, these values are combined in a quantity called the multiple environment conservatism ratio (MECR) given by:

$$MECR = \frac{\sum_{J=1}^{N} CBI_j}{N} \tag{3}$$

Thus, a MECR value of one indicates that the test was always conservative, and a zero value would indicate that the laboratory test was never conservative for any of the field environments. The MECR ratios were computed for SAA and SIS data collected as X axis inputs to the component in the three lab tests and the seven field tests. This data is shown in Figures 8A and 8B. Figure 8A shows that the low frequency test covers the field data up to 1300 Hz. The high frequency tests are conservative for only 70 to 80 percent of the tests at frequencies above 1500 Hz. The MECR for SIS in Figure 8B reveals a frequency range between 950 and 1100 Hz where none of the tests were conservative. Both plots indicate that the Y axis test is comparable to the X axis test in providing an X axis input to the component.

## SPECIFYING CONSERVATISM REQUIREMENTS

While the MECR ratio indicates whether the test was nominally conservative, it does not indicate the degree to which an overtest or an undertest was experienced during the test. This can only be done once the analyst has selected a desired level of conservatism for the test. Specifying the desired level of conservatism involves selecting an IOC value and then calculating an overtest factor (OTF) [8] defined as:

$$OTF = \frac{\overline{C}_T}{\overline{C}_{T,I}} \qquad , \; IOC = I \tag{4}$$

where $\overline{C}_{T,I}$ is the mean characterization of the test data which will produce the desired IOC value of I. In other words, the OTF indicates how many times greater the mean test characterization was than it had to be to satisfy the conservatism criterion. The OTF is calculated assuming that $\overline{C}_T$ varies linearly and that $\sigma_T$

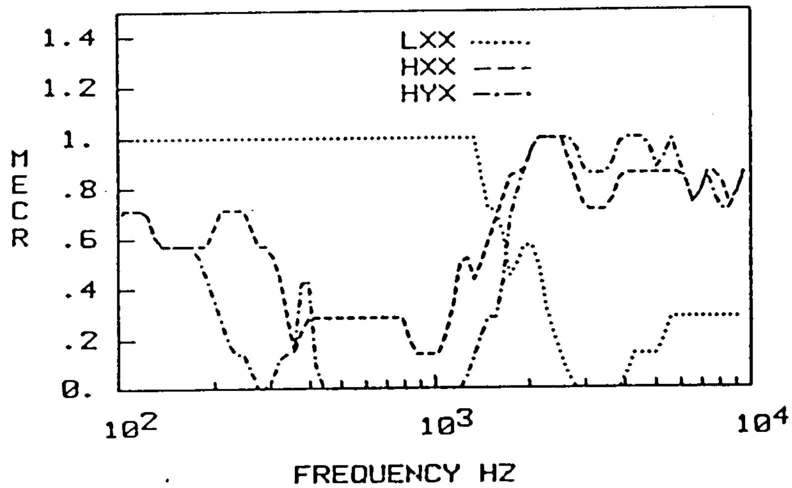



FIGURE 8A.
MERC FOR X AXIS SAA RESPONSE
(DAMPING=0.05)

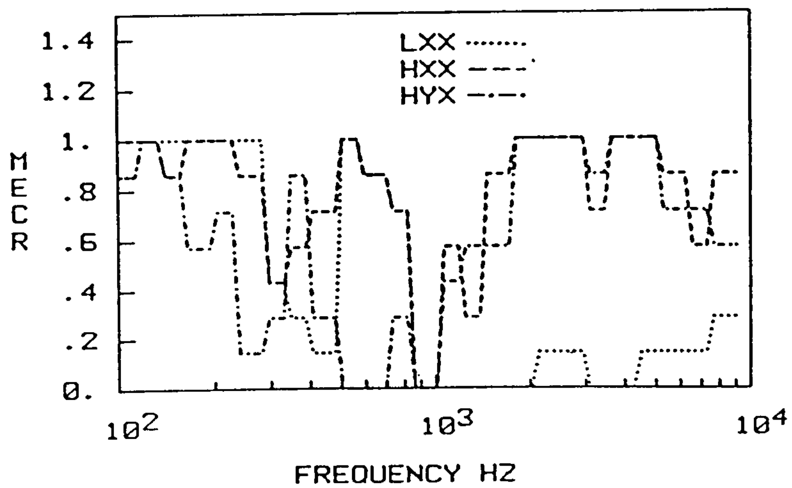



FIGURE 8B.
MECR FOR X AXIS SIS RESPONSE
(DURATION=0.02)

remains constant regardless of a change in $\overline{C}_T$. An overtest occurs if OTF is greater than one. An OTF less than one indicates an undertest.

## OVERTEST ANALYSIS

Assuming that an IOC of one is the desired degree of shock test conservatism, the OTFs for SAA and SIS were computed for each combination of field test and lab test. The minimum of these OTF curves are shown in Figures 9A and 9B. Significant overtesting is apparent in both plots at the resonant frequencies of the high and low frequency plates.

In order to get a closer look at where the overtest and undertest is occurring, a multiple environment overtest ratio (MEOR) can be defined:

$$\mathrm{MEOR} = \frac{\sum_{j=1}^{N} \mathrm{OBI}_j}{N} \qquad (5)$$

where N is the number of field environments and the overtest binary index is given by:

$$\mathrm{OBI}_j = \begin{cases} 0, & \mathrm{OTF}_j < 1 \\ 1, & \mathrm{OTF}_j \geq 1 \end{cases} \qquad j = 1,N \qquad (6)$$

The MEOR plots for SAA and SIS are shown in Figures 10A and 10B, respectively. Note the general similarity between Figures 10A and B and the MECR plots in Figures 8A and 8B. The plot amplitudes have decreased in the MEOR curve where the lab tests are only marginally conservative. Figures 11A and 11B portray the SAA and SIS MEOR ratios for the Y axis tests. The Y axis tests indicate that the desired level of conservatism was reached for nearly the entire SAA spectrum (Figure 11A). The Y axis SIS spectrum MEOR ratio, however, reveals a significant area of undertest in the 900 to 1000 Hz region.

## FAILURE MODEL BASIS FOR INTERPRETING RESULTS

Final interpretation of the conservatism analysis results obtained so far requires the analyst to assume a failure model for the component being tested. For example, if the component has a failure mode in the X axis associated with a certain frequency, the analyst looks at Figures 9A or 9B to determine the value for the minimum overtest factor at that frequency. If an overtest occurs, consideration might be given to modifying the test input accordingly. If an undertest is observed, then Figures 10A or 10B indicate what percentage of the field tests experience an undertest at this frequency.

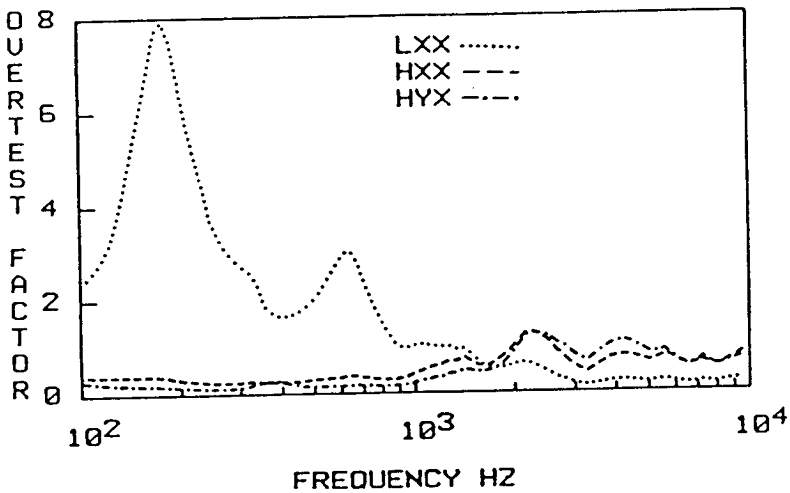



FIGURE 9A.
COMPARISON OF X AXIS SAA OTF MINIMUMS FOR THREE TEST INPUTS
(DAMPING=0.05)

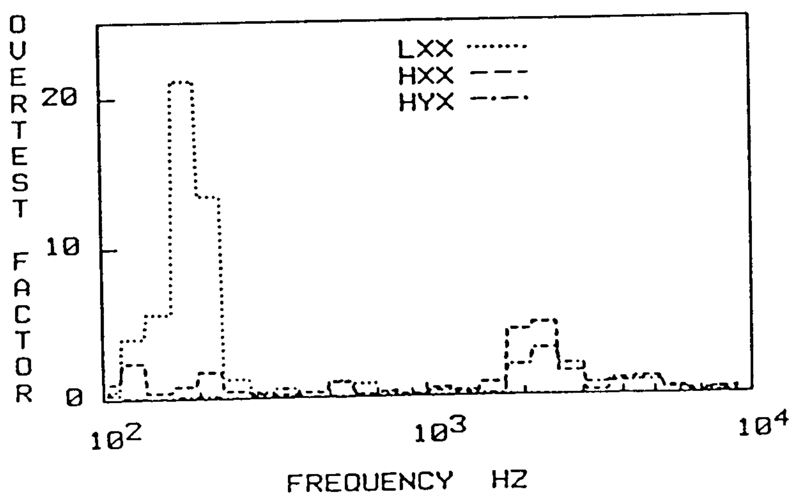



FIGURE 9B.
COMPARISON OF X AXIS SIS OTF MINIMUMS FOR THREE TEST INPUTS
(DURATION=0.02)

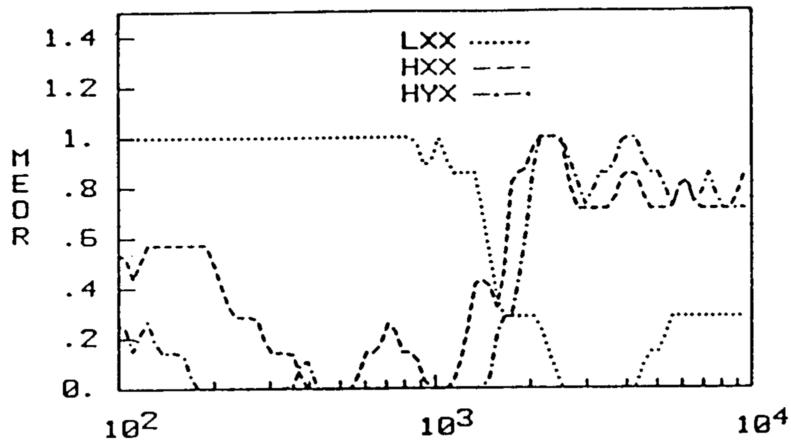



FIGURE 10A.
MEOR (IOC=1) FOR X AXIS SAA RESPONSE
(DAMPING=0.05)

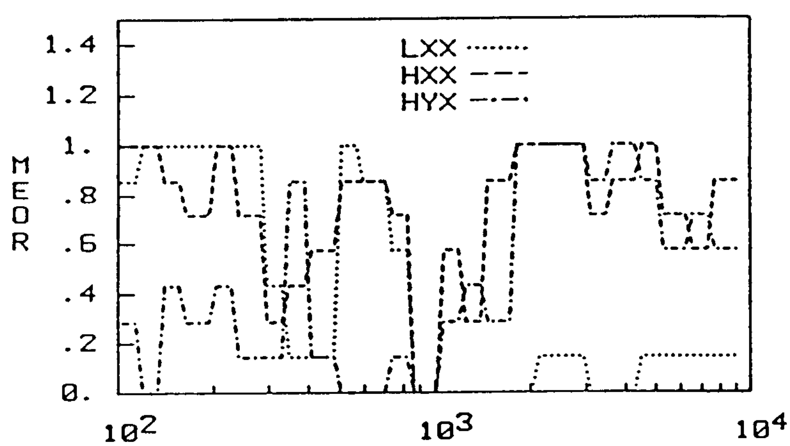
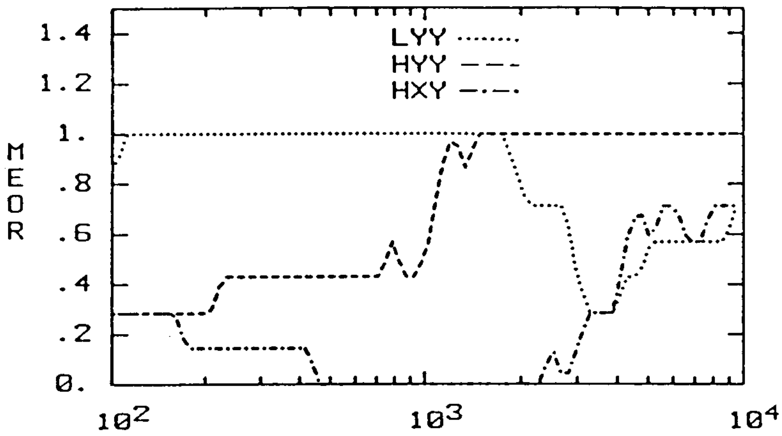
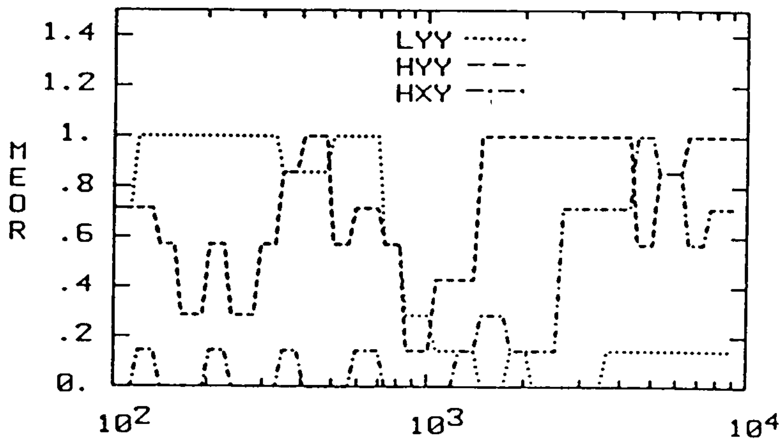



FIGURE 10B.
MEOR (IOC=1) FOR X AXIS SIS RESPONSE
(DURATION=0.02)




FREQUENCY HZ
FIGURE 11A.
MEOR (IOC=1) FOR Y AXIS SAA RESPONSE
(DAMPING=0.05)




FREQUENCY HZ

FIGURE 11B.
MEOR (IOC=1) FOR Y AXIS SIS RESPONSE
(DURATION=0.02)

When the sensitivity of the component is not well understood, another approach is to summarize the conservatism data by assuming a general type of failure model, such as a brittle displacement sensitive structure or a fatigue/multicycle sensitive structure. The conservatism analysis in the X axis is summarized in Tables I and II for each of these failure models. Table IA and Table IIA present overtest and undertest weights as bar charts and weighted OTF numerical values for each of the field/lab test comparisons. The overtest weight WTO is given by:

$$WTO = \frac{\sum_{i=1}^{K} Doi}{\sum_{j=1}^{L} Daj} \tag{7}$$

where:

Doi = ith abcissa delta increment where an overtest condition exists for the shock characterization

Daj = jth abcissa delta increment for the shock characterization

K = total number of abcissa overtest delta increments

L = total number of abcissa delta increments.

For discrete characterizations like ranked peaks, the WTO is the ratio of the number of ranked peaks which were an overtest to the total number of ranked peaks under study. For frequency domain characterizations, the WTO is the ratio of the cumulative frequency range where an overtest condition occurred to the total frequency range being considered. An undertest weight WTU is defined in a parallel manner. Note that WTO and WTU must sum to one. The shaded rectangle is positioned in the bar depending on the relative values of WTO and WTU. Complete undertest is indicated by a shaded box shifted entirely to the left, and complete overtest is indicated by a shaded box situated on the right end of the bar chart. This display of the data offers the analyst the opportunity to see the range of test conservatism. The weighted OTF values OTFw are shown on each side of the bar chart and are defined as:

$$OTFw = \begin{cases} WTO * \dfrac{\sum_{i=1}^{K} OTFi}{K} & OTFi \geq 1 \\[2ex] WTU * \dfrac{\sum_{i=1}^{L-K} OTFi}{L-K} & OTFi < 1 \end{cases} \tag{8}$$

## TABLE IA.

### SUMMARY OF OVERTEST FACTOR WEIGHTS AND WEIGHTED OTFS BRITTLE AND DISPLACEMENT SENSITIVE STRUCTURES

LXX HXX HYX

| | MAX PEAK G UNDER TEST | MAX PEAK G OVER TEST | SAA 100–1000 HZ UNDER TEST | SAA 100–1000 HZ OVER TEST | SIS 100–1000 HZ UNDER TEST | SIS 100–1000 HZ OVER TEST |
|---|---|---|---|---|---|---|
| | 0.00 | 1.51 | 0.00 | 5.32 | 0.10 | 14.87 |
| B1 | 0.00 | 3.29 | 0.47 | 0.01 | 0.25 | 5.18 |
| | 0.00 | 3.39 | 0.28 | 0.00 | 0.19 | 0.63 |
| | 0.00 | 1.15 | 0.09 | 3.35 | 0.14 | 12.37 |
| B2 | 0.00 | 2.51 | 0.35 | 0.00 | 0.28 | 1.95 |
| | 0.00 | 2.58 | 0.21 | 0.00 | 0.20 | 0.16 |
| | 0.00 | 1.55 | 0.00 | 7.79 | 0.17 | 20.00 |
| B3 | 0.00 | 3.25 | 0.65 | 0.00 | 0.25 | 12.08 |
| | 0.00 | 3.45 | 0.37 | 0.00 | 0.24 | 1.29 |
| | 0.55 | 0.00 | 0.00 | 17.22 | 0.18 | 20.00 |
| NB1 | 0.00 | .121 | 0.40 | 0.97 | 0.12 | 9.92 |
| | 0.00 | 1.24 | 0.59 | 0.16 | 0.13 | 1.13 |
| | 0.00 | 1.14 | 0.00 | 11.73 | 0.18 | 7.20 |
| NB2 | 0.00 | 2.49 | 0.49 | 0.30 | 0.14 | 1.70 |
| | 0.00 | 2.57 | 0.50 | 0.02 | 0.24 | 0.00 |
| | 0.45 | 0.00 | 0.00 | 10.61 | 0.19 | 20.00 |
| NB3 | 0.98 | 0.00 | 0.57 | 0.37 | 0.25 | 4.43 |
| | 0.00 | 1.01 | 0.57 | 0.00 | 0.40 | 0.36 |
| | 0.00 | 1.09 | 0.00 | 11.22 | 0.18 | 17.93 |
| NB4 | 0.00 | 2.38 | 0.68 | 0.17 | 0.32 | 2.22 |
| | 0.98 | 0.00 | 0.57 | 0.37 | 0.25 | 4.43 |

## TABLE IB.

### SUMMARY OF OVERTEST FACTOR WEIGHTED AVERAGES BRITTLE AND DISPLACEMENT SENSITIVE STRUCTURES

LXX HXX HYX

| | MAX PEAK G UNDER TEST | MAX PEAK G OVER TEST | SAA 100–1000 HZ UNDER TEST | SAA 100–1000 HZ OVER TEST | SIS 100–1000 HZ UNDER TEST | SIS 100–1000 HZ OVER TEST |
|---|---|---|---|---|---|---|
| | 0.14 | 0.92 | 0.01 | 9.61 | 0.16 | 16.05 |
| ALL | 0.14 | 2.16 | 0.51 | 0.26 | 0.23 | 5.36 |
| | 0.14 | 2.04 | 0.44 | 0.08 | 0.23 | 1.14 |
| | 0.00 | 1.40 | 0.03 | 5.49 | 0.14 | 15.74 |
| B | 0.00 | 3.02 | 0.49 | 0.00 | 0.25 | 6.41 |
| | 0.00 | 3.14 | 0.29 | 0.00 | 0.21 | 0.69 |
| | 0.26 | 0.56 | 0.00 | 12.69 | 0.18 | 16 28 |
| NB | 0.25 | 1.52 | 0.53 | 0.45 | 0.21 | 4.57 |
| | 0.25 | 1.21 | 0.56 | 0.14 | 0.25 | 1.48 |

## TABLE IIA.

SUMMARY OF OVERTEST FACTOR WEIGHTS AND WEIGHTED OTFS
FATIGUE AND MULTICYCLE SENSITIVE STRUCTURES

| | | MAX 5 PEAK G UNDER TEST | MAX 5 PEAK G OVER TEST | RMS OVERALL UNDER TEST | RMS OVERALL OVER TEST | ALL SIS UNDER TEST | ALL SIS OVER TEST |
|---|---|---|---|---|---|---|---|
| B1 | LXX | 0.33 | 0.83 | 0.00 | 1.50 | 0.24 | 1.33 |
| | HXX | 0.19 | 1.56 | 0.00 | 2.79 | 0.05 | 9.93 |
| | HYX | 0.00 | 2.10 | 0.00 | 3.05 | 0.05 | 8.86 |
| B2 | LXX | 0.49 | 0.44 | 0.00 | 1.14 | 0.20 | 1.26 |
| | HXX | 0.18 | 1.21 | 0.00 | 2.12 | 0.05 | 8.68 |
| | HYX | 0.00 | 1.70 | 0.00 | 2.32 | 0.05 | 7.94 |
| B3 | LXX | 0.19 | 1.10 | 0.00 | 1.55 | 0.06 | 20.00 |
| | HXX | 0.00 | 1.87 | 0.00 | 3.25 | 0.06 | 20.00 |
| | HYX | 0.00 | 2.29 | 0.00 | 3.45 | 0.05 | 20.00 |
| NB1 | LXX | 0.43 | 0.00 | 0.55 | 0.00 | 0.12 | 5.71 |
| | HXX | 0.41 | 0.24 | 0.00 | 1.02 | 0.21 | 6.13 |
| | HYX | 0.54 | 0.25 | 0.00 | 1.12 | 0.17 | 1.64 |
| NB2 | LXX | 0.18 | 0.96 | 0.00 | 1.13 | 0.17 | 0.64 |
| | HXX | 0.00 | 1.66 | 0.00 | 1.23 | 0.05 | 5.07 |
| | HYX | 0.00 | 2.04 | 0.73 | 0.00 | 0.05 | 5.28 |
| NB3 | LXX | 0.43 | 0.00 | 0.45 | 0.00 | 0.18 | 3.01 |
| | HXX | 0.63 | 0.00 | 0.83 | 0.00 | 0.35 | 2.14 |
| | HYX | 0.56 | 0.20 | 0.91 | 0.00 | 0.25 | 0.99 |
| NB4 | LXX | 0.30 | 0.64 | 0.00 | 1.10 | 0.19 | 1.83 |
| | HXX | 0.17 | 1.22 | 0.00 | 2.05 | 0.15 | 5.30 |
| | HYX | 0.63 | 0.00 | 0.83 | 0.00 | 0.35 | 2.14 |

## TABLE IIB.

SUMMARY OF OVERTEST FACTOR WEIGHTED AVERAGES
FATIGUE AND MULTICYCLE SENSITIVE STRUCTURES

| | | MAX 5 PEAK G UNDER TEST | MAX 5 PEAK G OVER TEST | RMS OVERALL UNDER TEST | RMS OVERALL OVER TEST | ALL SIS UNDER TEST | ALL SIS OVER TEST |
|---|---|---|---|---|---|---|---|
| ALL | LXX | 0.34 | 0.57 | 0.14 | 0.92 | 0.17 | 4.83 |
| | HXX | 0.23 | 1.11 | 0.12 | 1.78 | 0.13 | 8.03 |
| | HYX | 0.26 | 1.23 | 0.35 | 1.42 | 0.14 | 6.69 |
| B | LXX | 0.34 | 0.79 | 0.00 | 1.40 | 0.18 | 7.53 |
| | HXX | 0.12 | 1.55 | 0.00 | 2.72 | 0.05 | 12.87 |
| | HYX | 0.00 | 2.03 | 0.00 | 2.94 | 0.05 | 12.27 |
| NB | LXX | 0.33 | 0.40 | 0.25 | 0.56 | 0.17 | 2.80 |
| | HXX | 0.30 | 0.78 | 0.21 | 1.07 | 0.19 | 4.41 |
| | HYX | 0.43 | 0.62 | 0.62 | 0.28 | 0.21 | 2.51 |

where L and K are defined above. The weighted OTF reflects both the amplitude of the OTF and the range over which either an undertest or an overtest occurs. Zero values of OTFw indicate that either WTO or WTU was zero for that range of the shock characterization. It should be noted that nonzero weighted overtest factors have been limited to values between 0.05 and 20 in an effort to keep extremely large overtest values from dominating summary averages of the weighted OTFs in Tables IB and IIB. These summary averages provide a measure of overall overtest or undertest characterized into three summary groups: all of the tests, the blast tests. and the nonblast tests. A review of these tables indicates that even though absolute conservatism is not achieved for all of the shock characterizations, the analyst is in a position to make a quantitative statement about the degree of overtest or undertest in an average sense. The low frequency X axis shock test is quite conservative for brittle and displacement sensitive structures as indicated in Table IB.

The high frequency content of the X and Y axes tests results in their achieving the desired level of conservatism for fatigue and multicycle sensitive components.

## CONCLUSION

Conservatism analysis techniques have been described and demonstrated in this paper which address the complication of trying to make a laboratory test qualify a component for use in multiple field environments. Quantitative measures are introduced which show when tests are conservative in both an absolute and average sense. Both the degree of undertest and the degree of overtest are tracked in this procedure. Alternatives to shock spectra are shown to give additional conservatism information to the engineer which may be crucial in determining the suitability of a shock test specification. The desired level of conservatism used in the analysis is always clearly stated, and can be modified to meet the requirements of the design engineer. Specifically, knowledge about the failure modes of a component may lead to lower level test specifications which do not meet the original criterion of enveloping shock spectra, but which can be rigorously shown to be conservative in terms of another shock characterization. Greater insight into the significance of the functional outcome of the test (i.e., did it break because the design is too weak or because the test specification is too conservative ?) and detailed knowledge of how the test specification can be altered to achieve a desired level of test conservatism are two significant benefits of performing a conservatism analysis. Future use of these techniques will produce qualification test inputs which venture beyond the realm of engineering judgment, and enter the state of soundly tailored test specifications founded on quantifiable measures of conservatism.

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